THE NICKEL BULLETIN

Monthly Abstracts of Recent Literature

JANUARY

1961 Volume 34 No. 1

THE MOND NICKEL COMPANY LIMITED

THAMES HOUSE MILLBANK LONDON SW1

Telephone: VICtoria 3888

Inclusion of the covers during the binding of previous issues of THE NICKEL BULLETIN has tended to interrupt the continuity of the respective volumes. It will be noted that the inside covers of this issue have been left free from BULLETIN material, and that the month and number of the issue appear above the contents list. These modifications have been introduced to enable the issues comprising Volume 34 to be bound without their covers.

THE NICKEL BULLETIN

Monthly Abstracts of Recent Literature

1961

Volume 34

THE MOND NICKEL COMPANY LIMITED
THAMES HOUSE MILLBANK LONDON SW1
Telephone: VICtoria 3888

JANUARY 1961 VOLUME 34 No. 1

INDEX

Nickel	Page
Hydrogen Precipitation of Nickel from Buffered Acid Solutions	4
Separation of Radiocobalt from Nickel	4
Determination of Zinc in Nickel	4
Mechanical Properties of Intermetallic Compounds: Literature Review	5
Influence of Temperature on the Mechanica Properties of Intermetallic Compounds	5
Fractographic Studies of NiAl and Ni_3Al	5
Extrusion of Intermetallic Compounds	6
Deformation Modes in Face-Centred-Cubic Superlattice Alloys	6
Intermetallic Compounds of the Transition Metals: High-Temperature Properties	6
Mechanical Properties of Ni_3Fe, Ni_3Ti, Ni_3Nb, and Ni_3Ta	6
Studies of NiAl and Ni_3Al	7
Electrodeposition and Other Coating Methods	
Recent Developments in Nickel Plating	8
Developments in Chromium Plating	8
Acceptance Requirements for Nickel/Chromium Plating	9
Meeting Specifications in Nickel/Chromium Plating	9
Non-Ferrous Alloys	
Structure and Properties of Titanium-Nickel Alloys	9
Study of the Yttrium-Nickel System	10
Rare-Earth Compounds with the $MgCu_2$ Structure	10
Microchemical Separation by the Ring-Oven Technique	10
Nickel-Iron Alloys	
Magnetization Reversal Process in Thin Nickel-Iron Films	11
Cast Iron	Page
Structural Changes During Heat-Treatment of Nickel-containing Cast Irons	11
Mould for Simultaneous Sampling of Metals for Spectrographic and Chemical Analysis	12
Constructional Steels	
Rôle of Stress in Hydrogen-Induced Delayed Failure in Nickel-Chromium-Molybdenum Steel	12
Heat- and Corrosion-Resisting Materials	
Phase Relationships in the Fe-Pb-Ni, Fe-Ni-C and Fe-Pb-Ni-C Systems	13
Surface Tension and Contact Angles of Copper-Nickel Alloys on Titanium Carbide	13
Influence of Processing Variables on the Properties of Dispersion-Hardened Nickel Alloys	13
Influence of Magnesium on the Oxidation Kinetics of a Copper-Nickel Alloy	14
Oil-Ash Corrosion of Stainless Steels in a Pilot-Scale Furnace	14
Methods of Combating Residual-Oil-Ash Corrosion	15
Corrosion Tests on Materials Exposed in Flue Gases from an Oil-Fired Furnace	15
Corrosion of Type 309 Steel in Furnace Flue Gas	15
Fireside Corrosion of Superheater Tubing in Coal-Fired Boilers	16
Corrosion of Superheaters and Reheaters in Coal-Fired Boilers	17
Resistance of Nickel-containing Nuclear-Power-Plant Tubing Materials to Corrosion by Boiler Sludge	17
Selective Corrosion of 'Inconel'	18
Stress-Corrosion Cracking of High-Strength Oil-Well Tubing	18
Identification of Chi and Sigma Phases in Stainless Steel	18
Nickel-Alloy Wire for Special Applications	19
Cold Heading of Nickel-containing Materials	19
Analysis	20
Patents	20

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Hydrogen Precipitation of Nickel from Buffered Acid Solutions

S. C. SIRCAR and D. R. WILES: 'Hydrogen Precipitation of Nickel from Buffered Acid Solutions.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 891–3.

The precipitation of metals and lower oxides from solution by hydrogen reduction has been actively investigated during the past few years. In the case of nickel, the kinetics of the precipitation have been studied in ammonia solution, but extension of this study to acid solutions has not attracted much interest, mainly because of the unfavourable thermodynamics at all but the lowest acidities. The present authors have recently completed a study, using a nickel catalyst, of the kinetics of hydrogen precipitation of nickel from acetate-buffered acidic solutions. The results of this study are recorded in the present paper.

At temperatures in the range 130°–160°C. the rate of reduction was found to be proportional to the catalyst area, the nickel-ion concentration, and the hydrogen pressure. Hydrogen ions had the effect of reducing the observed rate, probably as a result of causing the reverse reaction (dissolution) to proceed. The experimental activation energy was found to be 25 kcal. per mole.

Separation of Radiocobalt from Nickel

R. MILLS and M. J. VERNON: 'Separation of Radiocobalt from Nickel.'

Analytica Chimica Acta, 1960, vol. 23, Oct., pp. 388–90.

In the work reported, which was undertaken in connexion with studies in the field of nuclear physics, the authors reinvestigated the classical cobaltinitrite method of separating and estimating cobalt in the presence of nickel.

The separation was complicated by the requirements of the nuclear study, which involved the irradiation of nickel metal with both high-energy γ radiation and fast neutrons. In the former case, it was required to determine the ratios of the $^{58}Ni\ (\gamma,p)^{57}Co$ and $^{58}Ni\ (\gamma,n)^{57}Ni$ yields, and, in the latter, the $^{58}Ni\ (n,np)^{57}Co$ and $^{58}Ni\ (n,2n)^{57}Ni$ yields. The critical requirements for these determinations were, therefore, fairly rapid separation (<1 hour), and, at the same time, reasonably complete cobalt removal (>99 per cent.), immediately following the irradiations.

An accurately measured aliquot of cobalt-nitrate solution containing 5 mg. cobalt was added to a solution of AnalaR nickel nitrate ($<0{\cdot}0005$ per cent. cobalt) containing 10 g. nickel. The standard separation procedures were then used to precipitate cobalt as potassium cobaltinitrite, and, after measured time intervals, the precipitates were filtered, washed, dissolved in 20 ml. $6N\ H_2SO_4$, and made up to 50 ml. in standard flasks. The samples were then analyzed colorimetrically at 625 mμ.

The results given indicate that the cobaltinitrite method satisfied the requirements of the given nuclear-physics problem, provided that a standing time of about 45 minutes was employed and the precipitating solution was not heated. The reproducibility of the procedure can be inferred from the fact that recovery was >99 per cent. in all cases.

Determination of Zinc in Electronic Nickel

E. G. TOWNDROW, R. HUTCHINSON, H. W. WEBB: 'The Determination of Zinc in Indium and Nickel.'

Analyst, 1960, vol. 85, Oct., pp. 769–70.

In studies in connexion with the determination of small amounts of zinc in indium used for semiconductor alloys, the authors evaluated the method generally advocated for separating the two metals (involving precipitation of indium by ammonia in the presence of ammonium chloride, to leave zinc in solution), and found that, despite repeated re-precipitation of indium hydroxide, recoveries of zinc were invariably low. Substitution of sodium hydroxide for ammonia resulted in even lower recoveries.

Subsequent investigation demonstrated that the method for determining zinc in lead–tin alloys described by BISHOP and LIEBMANN (ibid., 1953, vol. 78, p. 117) was adaptable to the determination of zinc (1) in indium and (2) in grades of nickel used for electronic purposes. Particulars of the procedures used in both determinations are given in the present note.

Mechanical Properties of Intermetallic Compounds: Symposium

'Mechanical Properties of Intermetallic Compounds.' Edited by J. H. WESTBROOK.

Published by *John Wiley and Sons, Inc.*, New York and London, 1960; 435 pp. Price $9.50; 76/-.

This book contains the proceedings of a Symposium on the Mechanical Properties of Intermetallic Compounds held, under the aegis of the Electrothermics and Metallurgy Division of The Electrochemical Society, at Philadelphia, May 1959.

The volume may, on the basis of subject matter, be divided into five categories. A review of the literature is followed by two papers concerned with the effects of crystal structure and temperature, and three in

which consideration is given to experimental techniques employed to study the mechanical behaviour of intermetallic compounds. The next four authors discuss the effects of dislocations and point defects, and the remaining chapters cover the mechanical phenomenology of specific compounds. Considerations of space preclude inclusion of abstracts of papers of no specific relationship to nickel-containing compounds; references to these papers are, however, listed below. The scope of the other papers is indicated in the abstracts following this list.

G.-M. SCHWAB: 'The Electronic Factor in Mechanical Strength', pp. 71–86.

L. GREEN, M. L. STEHSEL and C. E. WALLER: 'Techniques for High-Temperature Tensile and Torsional Testing of Refractory Materials', pp. 121–140.

N. BROWN: 'The Interaction Between Dislocations and the Superlattice', pp. 177–191.

D. W. PASHLEY and A. E. B. PRESLAND: 'Electron-Microscope Observations of the Domain Structure in an Ordered Copper–Gold Alloy', pp. 211–228.

E. M. GRALA and J. B. McANDREW: 'Effects of Radiation on Properties of TiAl', pp. 229–243.

J. J. DUGA: 'Plastic Deformation of InSb', pp. 244–264.

R. F. POTTER, J. H. WASILIK and R. B. FLIPPEN: 'Mechanical and Electromechanical Properties of Indium Antimonide', pp. 265–296.

A. J. STONEHOUSE, R. M. PAINE and W. W. BEAVER: 'Mechanical Properties of Some Transition-Element Beryllides', pp. 297–319.

D. J. MACK, A. J. BIRKLE and W. L. KRUBSACK: 'Plasticity of the Complex-Cubic Gamma-2 Phase of the Copper–Aluminium System', pp. 320–336.

Mechanical Properties of Intermetallic Compounds: Literature Review

J. H. WESTBROOK: 'Mechanical Properties of Intermetallic Compounds: A Review of the Literature', pp. 1–69; disc., pp. 69–70.

In this critical review of the literature (based on a *bibliography* of 164 items), the author discusses the information available on the mechanical properties of intermetallic compounds in sections covering: attempts which various workers have made to systematize properties; elastic behaviours; hardening mechanisms (subdivided into order and domain hardening, defect hardening, strain hardening, solid-solution alloying, strain-ageing and relaxation effects, and phase-transformation hardening mechanisms); crystallography and micrography of deformation and fracture (including reference to experimental techniques, slip, deformation bands, twinning and fracture); and development programmes based on intermetallic compounds.

Much of the data considered in connexion with hardening mechanisms relates to nickel-containing intermetallic compounds.

Influence of Temperature on the Mechanical Properties of Intermetallic Compounds

E. M. SAVITSKII: 'Effect of Temperature on the Mechanical Properties of Intermetallic Compounds', pp. 87–118; disc., pp. 118–20.

The effects of temperature are illustrated by data available on, *inter alia*, the compounds NiSi and Ni_2Si.

Fractographic Studies of NiAl and Ni_3Al

R. W. GUARD and A. M. TURKALO: 'Fractographic Studies in NiAl and Ni_3Al', pp. 141–59; disc., p. 160.

Although a high melting point, high hardness and extreme brittleness have long been regarded as characteristic of intermetallic compounds, consideration of their crystal structure suggests the possibility that certain compounds may possess some chance of being ductile. In the study now reported, the nature of fracture surfaces in NiAl and mixtures of NiAl and Ni_3Al was examined in the hope of contributing to an understanding of the mechanism of brittle fracture and of determining ways of increasing ductility to a usable level. (The compounds NiAl and Ni_3Al were selected for investigation because both are known to show some ductility as single crystals, and because Ni_3Al is face-centred cubic, and, consequently, should have a good possibility of possessing ductility, while NiAl, being body-centred cubic, would be expected to behave in a similar manner to iron and steels, which have been the subject of much study.)

The compositions of the specimens studied are shown below:

Ni at %	Al at %	Structure	Impact Energy (in.-lb.)
50	50	Stoichiometric NiAl	1
61	39	Transformed NiAl	1
65	35	Transformed NiAl	1
75	25	90 Ni_3Al/10 NiAl	12
72	28	65 Ni_3Al/35 NiAl	8
69	31	25 Ni_3Al/75 NiAl	4

All the specimens were annealed for 24 hours at 1175°C., and then quenched to room temperature to retain the transformation product observed in NiAl. Fractures were effected at room temperature, using N.A.S.A. drop-test specimens. Replicas of fracture surfaces were subjected to electron-micrographic examination.

This examination revealed the features which would be anticipated on the basis of previous investigation of fractures in body-centred-cubic and face-centred-cubic metals. River-pattern and cleavage steps were evident in NiAl, and shear failures were invariably observed in Ni_3Al. The features observed on the fracture surface adequately reflected the manner in which the fracture crack propagated. From the results presented it is concluded that:

'1. The b.c.c. NiAl fractures primarily by cleavage, except where impurities cause grain-boundary weakness.

'2. Even when severely constrained in the matrix of NiAl, the particles of Ni_3Al fracture in a ductile manner, with considerable local deformation.

'3. When the NiAl is an acicular transformation product, the fracture will take place along the platelet interface as well as by cleavage within the plates.

'4. The fact that there is evidence of deformation in the cleavage fracture of NiAl near grain boundaries where the crack slows down, or at other discontinuities in the structure, indicates that one might observe a transition from brittle to ductile failure in NiAl at elevated temperatures.

'These conclusions, based on the observations of the fracture surfaces, together with the small amount of data on the impact energies, indicates that there is some hope of obtaining a ductile aggregate of NiAl and Ni_3Al if the structure can be refined and the impurity content reduced.'

Extrusion of Intermetallic Compounds

D. L. WOOD: 'Extrusion of Intermetallic Compounds', pp. 161–174; disc., pp. 175–6.

In connexion with a research programme directed towards identification of the origin of brittleness in polycrystalline intermetallics, and towards elucidation of the factors affecting the flow process in such materials, experiments were carried out to investigate the feasibility of making a large number of sound reproducible specimens by extrusion. The relevant experiments, reported by the present author, were carried out on NiAl, AgMg and Bi_2Tl.

The factors involved in the successful extrusion of the three compounds are discussed, and micrographs are presented to illustrate the structural features of the extruded material. The paper includes data derived from tensile tests on Bi_2Tl and AgMg.

Deformation Modes in Face-Centred-Cubic Superlattice Alloys

T. TAOKA, Y. YASUKÔCHI and R. HONDA: 'Deformation Modes in Face-Centred-Cubic Superlattice Alloys', pp. 192–210; disc., p. 210.

The work reported was initiated to determine (1) whether the surface structure of slip (i.e., an elementary structure or large sharp slip) depends on differences in the actual internal process of slip or in the experimental conditions (e.g., surface structure, temperature, rate of deformation), and (2) whether the internal process of slip in metals is 'homogeneous' or 'inhomogeneous'.

On the basis of data derived from experiments carried out on face-centred-cubic superlattice alloys (Ni_3Mn, Ni_3Fe, Pt_3Co and Cu_3Au), the authors conclude: (1) that the two types of slip pattern (the elementary structure and large sharp slip) observed on the surface of the superlattice alloys in the different order states appear to depend on the difference in atomic arrangements, and that these patterns reveal the actual slip behaviour in the interior of the crystals; (2) that, during the plastic deformation of superlattice alloys, slip takes place by one atomic distance on successive planes (i.e., the mode of slip in the interior of ordered face-centred-cubic crystals is not 'inhomogeneous' but 'homogeneous').

Intermetallic Compounds of the Transition Metals: High-Temperature Properties

R. D. GRINTHAL: 'Intermetallic Compounds of the Transition Metals and their High-Temperature Properties', pp. 337–42; disc., p. 343.

Some intermetallic compounds have pronounced congruent melting points which are, in a few cases, higher than that of either parent metal. This attractive characteristic, and the possibility that some compounds produced from two malleable metals might retain the ductility of the constituent elements, led to an investigation of the suitability of various intermetallic compounds for high-temperature applications.

After a preliminary survey of the literature and published phase diagrams, a chart was developed from which it was possible to tell whether various binary combinations of the transition metals formed compounds or solid solutions. Those that did form intermetallic compounds were rejected if the melting point of the compound was below 1400°C. Of the many possible combinations, only a very few showed promise for high-temperature use, and none was outstanding in comparison with some of the more commonly used carbides, borides and silicides.

The aluminides, and, in particular, NiAl, are discussed by the author as one of the more interesting groups of intermetallic compound investigated. Several attempts were made to improve the elevated-temperature creep-resistance and the impact strength of NiAl by addition of small amounts of a third metal (chromium, niobium, titanium or zirconium). The results summarized (*see* table on p. 7) do not, it is considered, indicate any significant improvement in behaviour under impact loading (although some isolated, non-reproducible results obtained from zirconium-containing NiAl indicated remarkably high impact strength).

The titanium-aluminium, lanthanum-aluminium, dysprosium - aluminium and chromium - titanium systems are also briefly commented upon.

Mechanical Properties of Ni_3Fe, Ni_3Ti, Ni_3Nb and Ni_3Ta

I. I. KORINLOV: 'The Mechanical Properties of Some Intermetallic Compounds of Iron and Nickel', pp. 344–55; disc., pp. 356–7.

Iron and nickel-base alloys are particularly liable to form intermetallic compounds from solid or liquid solutions. In the iron-nickel system, the formation of the compound Ni_3Fe from solid solution is well established, as is the formation of Ni_3Al, Ni_3Ti, Ni_3Nb and Ni_3Ta during crystallization of the corresponding liquid binary alloys. In this paper, the author summarizes the results of an investigation of (1) the mechanical properties of iron-nickel alloys in the region of the compound Ni_3Fe, and (2) the creep resistance of Ni_3Ti, Ni_3Nb and Ni_3Ta.

In the first test programme the alloys were subjected to tensile and hardness tests at room temperature, and to creep- and long-time rupture tests at 450° and 650°C. The relative creep-resistance of the three compounds studied in the second series of tests was evaluated at 800°C. and a stress of 6 kg./mm.^{2}.

Mechanical Properties of Intermetallic Compounds
(*See abstract on p. 6*)

Material	Modulus of Transverse Rupture p.s.i.		Impact Strength	Hardness	Electrical Resistivity	Density	
	20°C.	1000°C.	in.–lb.	R_A	micro-ohm-cm.	g./cc.	%
NiAl	140,000	90,000	2	67	22	6·0	—
+6% Cr	69,000	112,000	4	71	40	5·9	97
+5% Nb	57,000	41,000	—	68	32	5·9	97
+4% Ti	54,000	100,000	1	73	30	5·8	96
+4% Zr	70,000	116,000	2	68	33	5·8	96

Specimens of pure nickel and saturated solid solutions of nickel with tantalum (7·5 per cent.) or with niobium (10 per cent.) were included in the tests for comparative purposes. In both investigations, creep-resistance was established by a simplified bend test, using a centrifugal machine.

On the basis of the data presented, the author concludes that, in the iron-nickel system, the Ni_3Fe compound is characterized by singular points on the composition/mechanical-property curves determined at room temperature. At 450°C., the Ni_3Fe composition corresponds to a maximum in creep-resistance and a minimum in long-time rupture strength (with brittle failure of the samples), while, at 650°C., alloys in the region of Ni_3Fe are characterized by a flat maximum on the composition/creep and the composition/long-time rupture-strength curves. The occurrence of the strength maximum at 650°C. in the region of the compound may, it is considered, be attributable to incomplete dissociation of the compound and the preservation of a short-range-ordered structure with a stronger chemical bond between atoms than in an ordinary random solid solution.

At 800°C., the Ni_3Ti, Ni_3Nb and Ni_3Ta compounds exhibited higher creep-resistance than pure nickel and its saturated solid solutions, a finding which is explained in terms of a stronger chemical bond among the atoms in the compounds than in pure nickel and its solid solutions.

Studies of NiAl and Ni_3Al

E. M. GRALA: 'Investigations of NiAl and Ni_3Al', pp. 358–402; disc., pp. 403–4.

In previous investigations (by MAXWELL and GRALA), nickel-aluminium alloys containing up to 30 wt. per cent. aluminium were successfully cast, and the properties of the intermetallics NiAl and Ni_3Al were determined on specimens in the as-cast condition (see *N.A.C.A. Tech. Note* 3259, 1954). In the investigation now reported, the properties of Ni_3Al and NiAl were studied before and after homogenization treatment, and the data obtained were compared with data available on their room-temperature properties in the as-cast condition.

Two composition falling within the Ni_3Al range were selected for testing (those containing 13·3 and 14·0 wt. per cent. of aluminium), and the hot-workability of the stoichiometric (13·3 wt. per cent.) Ni_3Al phase was assessed in rolling and swageing experiments. The NiAl phase was regarded as of particular interest, (a) because the stoichiometric composition (31·5 wt. per cent. aluminium) possesses a melting point of 1640°C., and (b) because it exists over a wide range of composition. The latter feature enabled the properties of the phase to be evaluated as a function of variation in composition over the range 25–33 wt. per cent. aluminium.

The tensile properties of as-cast specimens were determined at room temperature; those of homogenized specimens were established both at room temperature and 815°C. Impact, hardness and stress-rupture tests were also carried out, and specimens were subjected to microstructural examination.

In the author's discussion of the data recorded in the paper, account is taken of the influence of the following factors: method of casting; homogenization; grain-size; composition (including, in the case of stoichiometric NiAl, addition of molybdenum).

Small variations in the composition of Ni_3Al were found to result in large changes in the strength and ductility of the compound at room and elevated temperatures. A fibrous fracture (an indication of micro-toughness) was observed in tensile, stress-rupture and impact testing. The 14 wt. per cent. aluminium alloy was found to be much stronger than the stoichiometric composition.

Significant changes were observed in the hardness, strength and ductility of the NiAl intermetallic over the range of compositions studied: stoichiometric NiAl was found to exhibit the lowest hardness and strength, while aluminium additions in excess of the stoichiometric composition increased the hardness and brittleness of the phase (an effect which is attributed to the formation of a defect structure in the alloy). None of the NiAl compositions exhibited room-temperature ductility, though stoichiometric NiAl showed tensile ductility at 650°C., and addition of 0·5 wt. per cent. of molybdenum resulted in observable tensile ductility in stoichiometric NiAl at room temperature, and large increases in room- and elevated-temperature tensile strength. The beneficial effects of molybdenum, which, it is considered, may

be a result of the combined effects of decreased grain-size and the possible tying-up of embrittling impurities, point the way, in the author's opinion, to a possible means of overcoming the room-temperature brittleness of the NiAl phase.

ELECTRODEPOSITION AND OTHER COATING METHODS

Symposium on Nickel/Chromium Plating

The papers abstracted below were presented at a One-Day Symposium on Nickel/Chromium Plating held, under the aegis of the Institute of Metal Finishing, at the Royal Festival Hall, London, on November 16, 1960. The papers are to appear in *Electroplating and Metal Finishing*, and a separate volume incorporating both texts and discussion is to be published by Robert Draper, Ltd. The attention of readers will, in due course, be directed to the appearance of these publications, but, in the meantime, some indication of the scope of the four papers (available to us in preprint form) is given below.

Recent Developments in Nickel Plating

H. C. CASTELL: 'Review of Recent Developments in Nickel Plating', 14 pp. + figures.

The performance of nickel/chromium electrodeposited coatings intended for service involving severely corrosive conditions has met with much criticism, and the fact that such complaints have, in many cases, been fully justified has led to determined attempts to develop techniques which will ensure improvement in corrosion-resistance. Most of the work in this connexion has been carried out in the United States, but useful contributions have come from other countries also, and there is now a mass of relevant information. The volume of work done, and the resultant literature, have been so great that the picture of the current position has become somewhat confused. With the aim of clarifying the position, the author in this paper reviews some of the major developments in nickel/chromium plating and comments on present and possible future trends. Interest has recently centred almost exclusively on the high-duty coatings required for the bright-finishing of motor-car parts and other equipment normally used out-of-doors, and emphasis is placed on this aspect.

Developments in decorative nickel plating over the past 10 years are outlined, and attention is directed to the findings of work carried out to study nickel and chromium coatings under corrosive atmospheric conditions. In the latter connexion, special consideration is given to the various techniques which have been developed to produce nickel coatings with improved corrosion-resistance, and to accelerated-test procedures which simulate service breakdown.

Other sections of the paper cover research on the mechanism of levelling, on brightness of deposits, and on throwing power as affected by organic substances added to plating solutions. The effects of sulphur in nickel deposits are also discussed.

Summarizing the points raised in his review, the author refers to the improved performances which research has shown to be obtainable (both in accelerated tests and in actual service) by use of duplex-nickel deposits (the first layer of which is sulphur-free). He concludes that, before final conclusions can be drawn from the developments reviewed, much more work needs to be carried out, particularly on the mechanism of the different types of corrosion to which a plated component may be subjected during service. He emphasizes, however, that, so far as the nickel component of a composite coating is concerned, thickness and uniformity of thickness are still of primary importance where corrosion-resistance is required. Although double-layer deposits can give additional protection, the responsibility for the production of serviceable coatings still lies with the plater and the designer, whose job it is to ensure that optimum mechanical properties, ample thickness, and uniformity of coating are consistently characteristic of all the plating produced.

Developments in Chromium Plating

S. W. BAIER: 'Recent Developments in Decorative Chromium Plating', 15 pp.

Introducing his subject, the author alludes to the fact that, in the past, the chromium component of a nickel/chromium composite coating was regarded only as a means of rendering the nickel tarnish-resistant, and, to a certain extent, of increasing abrasion-resistance. Little attention was paid to the contribution of the thin chromium layer, *per se*, to the corrosion-resistance of the composite coating. As a result of recent endeavours to improve the corrosion-resistance of nickel/chromium coatings, however, the rôle played by the chromium overlay has attracted close attention, and this paper is concerned largely with the information available in this respect.

The author first briefly reviews the factors which led to the use of a chromium overcoating as a final finish for nickel-plated components, and then discusses the events and research which culminated in the recognition of the importance of the chromium component and in the development of improved chromium-plating solutions. In this connexion, attention is drawn to work (carried out by The British Non-Ferrous Metals Research Association) which formed the basis for development of H.T.H.R.* chromic-acid/sulphuric-acid solutions capable of producing crack-free chromium deposits. The optimum plating conditions established for these solutions are outlined, and recommendations are made with respect to the thickness to which the chromium should be deposited for satisfactory service. Reference is also made to work undertaken

* High temperature, high ratio.

to evaluate the corrosion-resistance of duplex-nickel and H.T.H.R. chromium composite coatings. The feasibility of depositing H.T.H.R. chromium using chromic-acid solutions with catalysts other than sulphuric acid (or sulphate) is considered, and the results of work in this connexion are noted.

In the closing sections of the review the author discusses the corrosion protection conferred by duplex-chromium (crack-free chromium + microcracked chromium) deposits and by 'sandwich-chromium' (chromium + nickel + chromium) deposits, critically reviews data derived from atmospheric-corrosion tests on nickel/chromium coatings incorporating H.T.H.R. chromium, and finally alludes to developments in barrel plating and spray-suppressing agents, and to the introduction of a 'self-regulating high-speed' chromium-plating solution involving the use of a mixed silicofluoride/sulphate catalyst.

Acceptance Requirements for Nickel/Chromium Plating

W. G. L. MILLER: 'Acceptance Requirements for Nickel/Chromium Plating', 11 pp.

The author, a member of the Chassis Division, Ford Motor Company, Ltd., introduces his subject by drawing attention to the important rôle played by nickel/chromium plating in the car industry. Forty years ago bright finishes had relatively little influence on car sales or on subsequent pride of ownership; nowadays nickel/chromium plating influences customer choice, and the service performance of plated components is one of the most important factors upon which the satisfaction of the owner and popular esteem depend. The present paper was written to outline 'the circumstances which have brought this change about, to consider some of the problems involved, and to show how the motor-car manufacturer devises and amends specifications and testing methods to meet the increasingly severe conditions to which plated components are submitted in service'.

The author first alludes to the dissatisfaction which, with the general acceptance of nickel/chromium plating by the car industry, resulted from the failure to appreciate the limitations of electroplating and from the exaggerated claims which were initially made with respect to the service capabilities of plated parts (e.g., that they needed no cleaning), and then goes on to discuss the developments which, in the last ten years, have greatly improved the quality of nickel/chromium deposits. In view of the critical effect of the substrate on the nature and degree of service failure, these developments are considered in sections covering nickel/chromium plating of, respectively, steel, copper alloys and zinc-base die castings.

The second part of the paper draws attention to the important contribution made by specifications in raising and maintaining the standard of nickel/chromium plating. Reference is made to the requirements of *B.S.* 1224:1959, and the factors involved in testing to specification are exemplified by a description of the system adopted by the author's own Company (tables summarizing the requirements of the Ford Motor Company's *P.*40 *Specification* are included in the paper). Notes on the B.N.F. Thickness Tester, the Magnegage Thickness Tester, and the 'Corrodkote', the salt-spray, the sulphur-dioxide, the acetic-acid/salt-spray and the copper-accelerated salt-spray tests end the review.

Meeting Specifications in Nickel/Chromium Plating

D. BOUCKLEY: 'Meeting Specifications in Nickel/Chromium Plating', 8 pp.

In recent years the trend towards the use of specifications in nickel/chromium plating and, particularly since the advent of *B.S.* 1224:1959, towards thicker deposits, has made available to the plater the means of meeting manufacturers' demands for coatings of higher quality. Experience has thrown light on the plating conditions which contribute to the attainment of this high quality, and the factors involved in plating to specification form the subjects of the present paper.

The principal of these factors (racking, the shape of parts, anode-to-cathode distances, current-density limitations, and throwing power) are considered, and the problems peculiar to copper plating, nickel plating and chromium plating are discussed in the light of practical experience.

Brief notes are included on stripping jigs, drying-out, corrosion-resistance, and handling and design of parts.

NON-FERROUS ALLOYS

Structure and Properties of Titanium-Nickel Alloys

J. W. BARTON, G. R. PURDY, R. TAGGART and J. GORDON PARR: 'Structure and Properties of Titanium-Rich Titanium-Nickel Alloys.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 844–9.

The authors report an investigation undertaken to obtain more information on transformations in quenched, quenched-and-tempered and isothermally-transformed specimens of titanium-nickel alloys containing up to 10 per cent. nickel.

Isothermal-transformation curves were determined for alloys containing 7–10 per cent. nickel, and cooling curves were obtained for quenched specimens containing up to 7 per cent. nickel. The mechanical properties of alloys containing 2, 5 and 10 per cent. nickel were established as a means of relating properties to microstructures. The curves presented are supplemented by photomicrographs illustrating the microstructures corresponding to the various heat-treatments studied.

Among the points discussed by the authors is the production of the precipitated and the martensitic hexagonal phases on quenching.

Surface Tension and Contact Angles of Copper-Nickel Alloys on Titanium Carbide

See abstract on p. 13.

Melting Point and Composition Data
(See abstract below)

Formula	Nominal Composition		Type of Melting	Temperature of Melting	
	Ni. at. %	Ni. wt. %		°C.	°F.
Y	—	—	Congruent	1509 ±5	2768 ±9
Y_3Ni	25·00	18·03	Incongruent	902 ±4	1656 ±7
Y_3Ni_2	40·00	30·56	Incongruent	820 ±4	1508 ±7
YNi	50·00	39·76	Congruent	1070 ±3	1958 ±5
YNi_2	66·76	56·90	Incongruent	1106 ±3	2023 ±5
YNi_3	75·00	66·44	Incongruent	1237 ±5	2259 ±9
Y_2Ni_7	77·78	69·79	Incongruent	1298 ±5	2368 ±9
YNi_4	80·00	72·53	Incongruent	1340 ±8	2444 ±14
YNi_5	83·33	76·75	Congruent	1430 ±5	2606 ±9
Y_2Ni_{17}	89·47	84·87	Incongruent	1330 ±10	2426 ±18
Ni	100	100	Congruent	1455 ±3	2651 ±5
Eutectic					
Y_3Ni-Y_3Ni_2	34·80	26·05	—	805 ±4	1481 ±7
YNi-YNi_2	57·50	47·18	—	950 ±3	1742 ±5
Y_2Ni_{17}-Ni	93·30	90·18	—	1285 ±5	2345 ±9

Study of the Yttrium-Nickel System

B. J. BEAUDRY and A. H. DAANE: 'Yttrium-Nickel System.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 854–9.

On the basis of data available on the alloying behaviour of rare-earth metals with the metals of the first transition series, and taking into account the large numbers of compounds in the cerium-nickel system, six or more compounds might be expected to form in the nickel-yttrium system. A consideration of Hume-Rothery's rules of alloying (based on size factor, electronegativity and valence) indicated low terminal solid solubility and possible compound formation. The present study was carried out to establish the validity of these predictions, and to throw light on the general alloying behaviour of yttrium with nickel. The system was studied by metallographic, thermal and X-ray methods.

Table I lists the melting points of the pure metals, and the composition and melting points of the intermetallic compounds and eutectics determined. The paper includes crystallographic data for YNi, YNi_2, YNi_3, YNi_5 and Y_2Ni_{17}.

The terminal solid solubility was found to be low.

Influence of Magnesium on the Oxidation Kinetics of a Copper-Nickel Alloy

See abstract on p. 14.

Rare-Earth Compounds with the $MgCu_2$ Structure

J. H. WERNICK and S. GELLER: 'Rare-Earth Compounds with the $MgCu_2$ Structure.'

Trans. Metallurigcal Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 866–8.

In this paper the authors report the results of crystallographic investigations (part of a continuing study of the magnetic properties and structures of binary systems involving the rare-earths) of a large number of new AB_2 compounds (in which A is a rare-earth or yttrium atom, and B is aluminium, manganese, iron, cobalt or nickel) having the cubic $MgCu_2$ structure (Laves phase).

In most of the compounds the interatomic distances were found to be normal; the lanthanide contraction was observed. In the compounds CeB_2 (B = iron, cobalt, nickel), cerium appears to have a valence substantially greater than 3; in $CeAl_2$, cerium appears to be trivalent. These results are ascribed to the loss of the 4f electron of cerium to the 3*d* band of iron, cobalt and nickel. Evidence for the existence of homogeneity ranges in these compounds is presented.

Microchemical Separation by the Ring-Oven Technique

W. I. STEPHEN: 'Analysis for Industry.'

Industrial Chemist, 1960, vol. 36, Aug., pp. 408–10; Sept., pp. 459–61.

The ring-oven technique was developed by Weisz as a simple method of separating substances, or groups

of substances, contained in a single drop of solution. As first described by Weisz, the technique was confined to inorganic substances, so that the separations were those of ions or groups of ions in solution (the minute amounts of material and the volumes of solution used cannot be adequately dealt with by conventional methods). The drop of test solution is placed on a filter paper, and one of the ions or groups of ions is fixed locally on the paper with some particular reagent. The unaffected ions can then be washed from the precipitate to the outer regions of the paper by capillarity. To render the separation technique generally applicable, a method was required which, without simultaneously enlarging the area of the original spot on the paper (i.e., without diminishing the concentration of the substances being washed out), would completely remove the soluble substances from a precipitate held on filter paper. The method developed by Weisz for this purpose involves the use of the 'ring oven', the principle of which depends entirely on constraining the enlargement of the moist area during the washing-out process by enclosing it within a hot boundary. Soluble substances can then be washed from the precipitate, using a quantity of solvent, and the solute is quantitatively collected on the paper at a previously determined region.

The present review is in three sections. The author first outlines the fundamentals of the ring-oven process, and then describes its use in qualitative testing. Finally, he discusses the application of the technique to quantitative or semi-quantitative analysis (in particular, he outlines its uses in combination with electrographic techniques or solvent-extraction procedures, and in identification of radioactive substances). In combination with electrographic techniques the method is stated to be suitable for analysis of, *inter alia*, nickel-base alloys, for identification of metallic coatings, and for the sorting of steels by detection of manganese, nickel, molybdenum and chromium.

Mechanical Properties of Intermetallic Compounds: Symposium

See abstract on p. 4.

NICKEL-IRON ALLOYS

Magnetization Reversal Process in Thin Nickel-Iron Films

M. PRUTTON: 'Observations of the Magnetization Reversal Process in Thin Films of Nickel-Iron, Using the Kerr Magneto-Optic Effect.'

Brit. Jnl. Applied Physics, 1960, vol. 11, Aug., pp. 335-8.

Use of the Kerr magneto-optic effect overcomes most of the disadvantages associated with the application of the colloidal-suspension technique to the study of the magnetization reversal process in thin ferromagnetic films: it is an inertialess method which gives the direction of magnetization within a domain, and the existing domain pattern is not altered because of the interaction between the polarized light and the material. Unfortunately the effect is so small that contrast between adjacent domains is low, and high magnifications cannot be used. The Kerr magneto-optic effect is most useful, therefore, when employed in conjunction with the powder technique, the latter giving detailed knowledge of the boundary regions, and the former giving information on the direction of magnetization within a domain. The investigation reported (the initial phase of a general study of the reversal process in thin films) was concerned with the use of the Kerr effect to study the magnetization reversal process in uniaxial thin films of nickel-iron alloys containing approximately 80 per cent. nickel.

The results suggest that the magnetization reversal process in a film orientated with its easy axis at an oblique angle to the applied field occurs in three stages: (1) coherent rotation until the angle is reached where a discontinuous jump in the orientation of the magnetization is expected to start; (2) domain nucleation and growth from this angle to the angle where the jump should finish; (3) coherent rotation until the magnetization lays along the field. The way in which some actual films differ from this model is discussed.

CAST IRON

Structural Changes During Heat-Treatment of Nickel-containing Cast Irons

H. WIEGAND and H. HENTZE: 'Structural Changes During the Heat-Treatment of Iron-Graphite Materials.'

Giesserei, Techn. Wissensch. Beihefte, 1960, No. 29, July, pp. 1629-38.

In the work described, the authors, with the aim of obtaining information which would throw light on the

Element %	GG-22	GG-30	GGG.A	GGG.B	GGG.C
C (Total)	3·49	3·14	3·54	3·42	3·42
C (Graphite)	2·91	2·49	3·16	—	2·65
Si	1·68	1·81	2·33	2·52	2·31
Mn	0·45	0·85	0·24	0·33	0·53
P	0·60	0·25	0·07	0·066	0·087
S	0·18	0·13	0·008	0·015	0·014
Mg	—	—	0·050	0·049	0·046
Ni	—	—	0·52	1·48	1·10
Cr	0·04	0·06	0·009	0·05	0·009
Mo	—	—	trace	—	—
Cu	0·05	0·08	0·05	0·06	0·03

variables involved in the commercial heat-treatment of cast iron, studied the influence of heat-treatment (both long-time and short-time) on the structure of the three pearlitic grades of cast iron noted on p. 11. Grade GGG had been treated to obtain a spheroidal-graphite structure.

The test programme involved two phases:

I. To study structural changes during long-time heat-treatment, specimens were exposed, for up to 15 hours, to temperatures in the range 575°–725°C., and, using dilatometric techniques, growth diagrams were determined, which, in conjunction with the results of metallographic and chemical studies, provided information on carbon diffusion.

II. The reactions involved in short-time heat-treatments were investigated by means of the end-quench test, an evaluation of the data obtained from which enabled the structure of an individual iron to be studied as a function of the temperature and rate of cooling.

The data obtained are recorded in a series of curves which are deemed of value in the commercial heat-treatment of cast iron. Their applications as control tools are discussed by the authors.

On the basis of the time/temperature/growth curves presented, decarburization of the pearlitic structure in, and the subsequent growth of, the three grades of iron can, within the limits of the data presented, be quantitatively determined as a function of time and temperature of heating. The transformation/cooling curves derived in phase II of the study may be used to select the cooling times necessary to obtain a specific structure.

Mould for Simultaneous Sampling of Metals for Spectrographic and Chemical Analysis

W. R. KENNEDY and R. N. SMITH: 'Process for Simultaneously Sampling Metals for Spectrographic and Chemical Analysis.'

Applied Spectroscopy, 1960, vol. 14, No. 2, pp. 53–4.

The materials subjected to spectrographic and chemical analysis by the Melting Department of the American Cast Iron Pipe Company include soft iron, malleable iron, spheroidal-graphite iron, 'Ni-Hard', 'Ni-Resist', low-alloy steel, carbon steel and stainless steel. With the acquisition of a new spectrographic-sample excitation stand, which entailed a change in the shape of the sample, it was decided, since the sampling procedures employed at the time left much to be desired, to investigate the feasibility of developing a sampling mould which would prove more satisfactory. Details of the mould finally developed are given in the present paper.

In assessing the efficacy of the mould, the authors allude to the fact that the response to chilling of the various grades of cast iron produced by their Company varies greatly. Nevertheless even samples of the most difficult iron to chill have at least a $\frac{1}{8}$-in.-deep chill at the surface where the spectrographic laboratory would make its analysis, and the metallurgical structure is the same for all types of iron cast in the mould. Results with steel are stated to be equally reproducible.

CONSTRUCTIONAL STEELS

Rôle of Stress in Hydrogen-Induced Delayed Failure in Nickel-Chromium-Molybdenum Steel

E. A. STEIGERWALD, F. W. SCHALLER and A. R. TROIANO: 'The Rôle of Stress in Hydrogen-Induced Delayed Failure.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 832–41.

The phenomenological characteristics of delayed failure in high-strength steel have been comprehensively investigated, and such failure has been attributed to the embrittling action of hydrogen. The initiation of a hydrogen-induced crack is believed to be dependent on two factors: stress-induced diffusion which produces appreciable segregation of hydrogen in a localized region; and the basic effect of hydrogen on the material (causing localized failure, i.e., a crack). The object of the investigation now described was to examine, with the aim of obtaining a clearer understanding of the rôle of stress in the delayed-failure process, the individual effects of stress-induced diffusion and the embrittling action of hydrogen.

Specimens of A.I.S.I. 4340 nickel-chromium-molybdenum low-alloy steel with various notch geometries were electrolytically charged (to introduce hydrogen), and then subjected to tensile tests in liquid nitrogen or delayed-failure tests at room temperature. Delayed-failure specimens were cathodically charged in 4 per cent. sulphuric-acid solution, cadmium-plated and then baked to homogenize the hydrogen distribution. To attain a uniform hydrogen content without baking, the tensile specimens were charged for 24 hours in a solution of 4 per cent. sulphuric acid containing a poison.

Above a particular threshold stress the conditions necessary for localized cracking were found to be essentially dependent only on the development of a critical hydrogen content: the basic relationship between hydrogen and stress is then virtually insensitive to the magnitude of the applied stress in the failure range. An anology drawn between (1) the stress-induced diffusion of carbon and nitrogen to the stress field surrounding a dislocation, and (2) the stress-induced diffusion of hydrogen to the stress field about a fracture embryo located at the region of maximum triaxiality, leads the authors to conclude that the number of hydrogen atoms which arrived at the critical region where fracture initiated was governed by the stress. A relationship between the applied stress is developed (though the scatter in the data has prevented any critical evaluation).

The lower critical stress is defined as the minimum stress necessary to produce sufficient hydrogen segregation to initiate a crack. Employing this definition and the Boltzmann distribution law, the minimum stress to produce failure is rationalized as a function of notch acuity, yield strength, initial hydrogen content, and temperature. For a given test temperature and hydrogen content, the interaction energy was constant and independent of notch geometry. Increase in notch acuity and strength level merely

permitted the development of the critical interaction energy at a lower applied load (resulting in a lower static-fatigue limit). Over the range studied [room temperature to −50°F. (−46°C.)], the influence of temperature on the lower critical limit has been predicted on the basis of the distribution law and the effects of temperature on the yield strength.

Stress-Corrosion Cracking of High-Strength Oil-Well Tubing

See abstract on p. 18.

Mould for Simultaneous Sampling of Metals for Spectrographic and Chemical Analysis

See abstract on p. 12.

HEAT- AND CORROSION-RESISTING MATERIALS

Phase Relationships in the Fe-Pb-Ni, Fe-Ni-C and Fe-Pb-Ni-C Systems

K. O. MILLER and J. F. ELLIOTT: 'Phase Relationships in the Systems Fe-Pb-Ni, Fe-Ni-C(Sat) and Fe-Pb-Ni-C; 1300° to 1550°C.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 900-10.

Since little information has been published on the phase diagrams of the Ni-Pb, Fe-Pb, Fe-Pb-Ni and Fe-Ni-Pb-C systems, the study described was undertaken to ascertain the important phase relationships in the temperature range 1300°-1550°C. Measurements were also made of the carbon-saturated systems in the hope that the results would assist in the interpretation of the systems without carbon. The data obtained from the simple equilibration of the various liquid and solid phases are presented in this paper.

The results indicate the influence of temperature and composition on the liquid miscibility gap in the Fe-Pb and Ni-Pb systems. Using a very wide gap in the Fe-Pb binary as a basis for comparison, it was found that additions of nickel tend to close, and additions of carbon to widen, the gap. The gap tends, at all compositions, to close with rise in temperature. (The theoretical considerations of these effects will be contained in a later paper.)

Surface Tension and Contact Angles of Copper-Nickel Alloys on Titanium Carbide

T. J. WHALEN and M. HUMENIK: 'Surface Tension and Contact Angles of Copper-Nickel Alloys on Titanium Carbide.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 952-6.

The investigation described was carried out to determine if the changes which occur in the electronic structure of solid copper-nickel alloys with changes in composition are reflected in the surface-tension values of the liquid alloys, to investigate wettability in the system copper/nickel/titanium carbide, and to throw light on the possible processes which occur during wetting in this system.

The sessile drop method was employed to measure the liquid surface tension, density, and contact angle of the liquid on the solid.

It was found that the relationship between composition and the contact angle of the alloys is adequately represented by a smooth curve. The addition of small amounts of titanium and carbon were found to have no effect on the surface tensions of copper-nickel alloys. Small additions of nickel to copper significantly reduced the contact angle of the alloy with titanium carbide. Nickel is shown to be adsorbed at the titanium-carbide/alloy interface.

Mechanical Properties of Intermetallic Compounds: Symposium

See abstract on p. 4.

Influence of Processing Variables on the Properties of Dispersion-Hardened Nickel

L. J. BONIS and N. J. GRANT: 'Influence of Processing Variables on the Properties of Nickel-Al_2O_3 Alloys.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 877-81.

Mechanical mixing of the appropriate powders provides one of the simplest and most inexpensive methods of preparing dispersion-strengthened metal/metal-oxide materials. Due to large differences in specific gravity, powder-particle diameters and other variables, difficulties have, however, been encountered in reproducing alloys and alloy properties. In the investigation now reported the following variables were studied in relation to dispersion-hardened nickel materials produced by mixing 5-μ nickel powder and 0·018-μ Al_2O_3, compacting, sintering and extruding: (1) blending techniques (cooling of powders during blending; attempts to discharge the electrostatic charges which were thought to contribute to agglomeration during high-speed blending); (2) blending time; (3) volume percentage of oxide present; and (4) sintering of compacts before extrusion. Specimens were subjected to tensile tests at room temperature and creep-rupture tests at 1500°, 1800°, 1900° and 2000°F. (815°, 980°, 1035° and 1095°C.).

The results presented are regarded as demonstrating the important rôle played by the variables studied in determining the structures and properties of the dispersion-hardened materials. If control is maintained over such factors as mixing time, mixing temperature, electrostatic charges and sintering, both the structures and properties obtained are rendered more reproducible. Structures produced under such control exhibit high strength at temperatures of 1500°F. (815°C.) and above, the temperature coefficient for the rupture strength being very low compared to that of conventional age-hardenable nickel-base alloys.

The dispersion-hardened materials are stated to be stronger at temperatures above 1800°F. (980°C.) than the best wrought nickel-chromium-base age-hardenable alloys currently in use in jet engines.

Influence of Magnesium on the Oxidation Kinetics of a Copper-Nickel Alloy

J. A. SARTELL, S. H. BENDEL and C. H. LI: 'The Effect of Oxide Microstructure on the Oxidation Kinetics of Cu-Ni-Mg Alloys.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 809-12.

In a previous paper (see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 1, p. 19) SARTELL *et al.*, reporting on the oxidation characteristics of a 62-38 copper-nickel alloy, showed that the oxide scale consisted of two layers: a thin layer of CuO outside a much thicker layer of Cu_2O in which particles of NiO were dispersed. Immediately beneath the oxide/metal interface there was an internally oxidized zone in which NiO particles were dispersed in a copper-rich alloy matrix. Experimental observations of the growth of the individual layers under isothermal conditions led to the conclusion that the rate-determining step in the oxidation of the alloy is the diffusion of anions through the Cu_2O layer. Since it has been reported that addition of magnesium to a 62-38 copper-nickel alloy decreases the oxidation rate, the investigation now reported was undertaken to determine the mechanism responsible for this improvement.

Small additions of magnesium were found greatly to reduce the oxidation of the alloy at temperatures in the range 500°-850°C. Metallographic examination of the oxide scale disclosed a continuous network [identified by X-ray diffraction as (Ni,Mg)O solid solutions] located along the former alloy grain boundaries. This network is presumed to result from the oxidation of a structure in which magnesium has segregated to the alloy grain boundaries, thereby causing the preferential nucleation of either MgO or a magnesium-rich (Ni,Mg)O solid solution at these locations. When the magnesium was not allowed to segregate, the NiO network did not form and oxidation proceeded either at the same rate as, or more rapidly than, the magnesium-free 62-38 copper-nickel alloy.

Oil-Ash Corrosion of Stainless Steels in a Pilot-Scale Furnace

N. D. PHILLIPS and C. L. WAGONER: 'Oil-Ash Corrosion of Superheater Alloys in a Pilot-Scale Furnace: Reduction by Use of Additives.'

Amer. Soc. Mechanical Engineers, Paper 59-*A*-281, 1959: 8 pp.

The corrosion problems associated with ash deposition in gas turbines and boilers burning residual fuel oil have been discussed extensively in the literature (see, for example, reviews by SCHAB and SLUNDER referred to in *Nickel Bulletin*, 1959, vol. 32, No. 3, p. 89; see also abstract in *Nickel Bulletin*, 1960, vol. 33, No. 4, pp. 86-7). Corrosion data published in the literature have been obtained mainly under the isothermal test conditions applicable to gas-turbine operation (in which the temperatures of the combustion gases and the metal are virtually equal). In boiler operation, however, the fact that the two temperatures are different has a significant effect on corrosion rates (and, incidentally, renders the application of gas-turbine corrosion data to the conditions involved in boiler service extremely difficult).

In order to investigate oil-ash corrosion under conditions where the gas temperatures and metal temperatures are different, and to determine methods of alleviating corrosion, a pilot-scale furnace was constructed which enabled alloys to be tested under closely controlled conditions of gas temperature, metal temperature, fuel composition (vanadium, sodium and sulphur content), and firing conditions. Provision was also made for evaluation of the inhibitive effects of various additives. In this paper the authors report the results of the tests performed to study the effect of fuel-oil composition and metal and gas temperature on corrosion of selected heat-resisting steels. They also present data on the effectiveness of various additives in reducing the severity of such corrosion.

A.I.S.I. Type 304, 310, 316 and 321 stainless steels (i.e., steels of 18-8, 25-20, 16-13-Mo and 18-10-Ti type) were selected for study. Four dry additives were employed as corrosion inhibitors: magnesium oxide, magnesium hydroxide, dolomite and kaolin. The influence of specimen and flue-gas temperatures was investigated over the ranges of, respectively, 1100°-1300°F. (595°-705°C.) and 1350°-2500°F. (735°-1370°C.), using steam-cooled tubular specimens exposed in a small boiler fired with natural gas and diesel oil containing various combinations of vanadium, sodium and sulphur.

The results are discussed in terms of the effects of: exposure time, exposure temperatures, steel composition, oil composition, ash-deposition rates, composition of the deposit and corrosion product, and inhibition by additives.

None of the steels tested is considered to have exhibited outstanding resistance to oil-ash corrosion under the temperature conditions studied (Type 310 steel did, however, indicate some promise for use at the higher temperatures).

Oil-ash corrosion of these materials was found to be dependent both on the specimen and gas temperature. An increase in the specimen temperature resulted in increased corrosion, but it is also shown that, for a given specimen temperature, higher gas temperatures have a similar effect. (It is believed that this effect is due to the fact that the bulk slag layer attains higher temperatures with increase in the gas temperatures, causing corrosion to proceed more rapidly, with a more fluid slag at the slag/metal interface.) The relationship between the combined corrosive effect of metal temperature and gas temperature is discussed in relation to specific fuel-oil compositions.

The data presented indicate that fuels containing less than 10 p.p.m. of vanadium gave rise to much

less corrosion than oils containing 150 p.p.m. or more; the amount of sodium present did not have such a significant influence on corrosion.

Addition of inhibitors (in the form of dry powder) reduced corrosion to the degree that, in their presence, steels at 1200°F. (650°C.) suffered less corrosion than at 1100°F. (595°C.) when they were not present. With specimen temperatures of 1200°F. [and over a gas temperature range of 1400°-2400°F. (760°-1315°C.)], the results indicate that the sum of the cations in the additive should be at least three times the vanadium content of the oil.

Methods of Combating Residual-Oil-Ash Corrosion

D. W. McDOWELL and J. R. MIHALISIN: 'New Developments for Handling the Fuel-Oil-Ash Corrosion Problem.'

Amer. Soc. Mechanical Engineers, 1960, *Paper* 60-*WA*-260; 8 pp.

The incidence of residual-oil-ash corrosion has been found to be particularly high where large quantities of bunker C oil have been used in industrial heating. Field tests have indicated that recently developed chromium-nickel alloys offer improved resistance to such attack, but, parallel with efforts to increase the corrosion-resistance of the materials of construction, work on the problem is continuing in such other directions as the application of protective coatings, inhibition of corrosion by use of inorganic additives aimed at raising the fusion point of the ash, changes in equipment design and operation [particular emphasis has been placed on the feasibility of maintaining the operating temperature at below 1200°F. (650°C.) and on the influence of the air/fuel ratio], and treatment of the oil to remove the deleterious vanadium, sodium and sulphur compounds. These approaches form the subjects of the present paper.

The cost of the oil treatments discussed is deemed to limit their applicability, while fully effective protective coatings have yet to be developed. The effectiveness of inorganic inhibitors has been found to vary with the operating conditions and the material tested, but, in general, use of compounds of magnesium, calcium, zinc, phosphorus and aluminium has produced the best results.

Much of the paper is given up to consideration of service and laboratory corrosion tests on various nickel-containing alloys and steels. (In the laboratory investigation, the opportunity was taken to evaluate the degree to which such tests simulate service conditions.) This test programme revealed the improvement in corrosion-resistance offered by a recently developed 60–40 chromium-nickel alloy* and showed the value of crucible tests in screening alloys for resistance to fuel-oil-ash corrosion. The $Na_3SO_4.V_2O_5$ crucible tests gave rise only to accelerated corrosion, while combinations of a sulphur-bearing gas and molten synthetic fuel-oil-ash constitutents, causing combined oxidation and sulphidation, more nearly simulated service experience.

* For further details of this alloy, see papers referred to in *Nickel Bulletin*, 1960, vol. 33, No. 8-9, p. 220.

Corrosion Tests on Materials Exposed in Flue Gases from an Oil-Fired Furnace

M. HANEEF: 'Corrosion Tests on Materials Exposed in Flue Gases from Oil Firing.'

Jnl. Inst. Fuel, 1960, vol. 33, June, pp. 285–94.

The problems of flue-gas corrosion and deposits have occupied the attention of power engineers for many years. The investigations now reported were undertaken to determine the relative corrosion rates exhibited by the following materials as a result of exposure to the flue gases from an oil-fired water-cooled furnace: carbon steel, normalized cast iron, annealed cast iron, the chromium-nickel-copper low-alloy steel 'Corten', and a 17-11-1·5 chromium-nickel-molybdenum stainless steel.

The specimens were exposed for 2, 6, 18 or 54 hours at surface temperatures of 180°, 140° and 110°C. The vanadium content of the fuel oil used was 60 p.p.m. The furnace operating conditions and the test procedures are described in detail.

The relationships determined between surface temperature and corrosion confirm the findings of other investigators. Tests of up to 54 hours' duration showed that corrosion/time curves could be expressed by the relation $y=c_1x^{c_2}$, where y is the corrosion loss (in mg.) from 100 cm.^{2} of the material, x is the exposure time in hours, and c_1 and c_2 are two coefficients whose values are given in the paper. Such short-term tests can, it is considered, be used to provide an indication of corrosion rates in boilers. In general, corrosion rates increased in the order: 'Corten', stainless steel, carbon steel, cast iron (normalized), cast iron (annealed).

Details are also given of supplementary tests run to study: (a) corrosion of a surface as a function of its temperature; (b) corrosion of cast iron before and after machining; (c) the effect, on the corrosion of a surface, of the angle of attack of the flue-gas stream; and (d) the effect, on the acid dewpoint, of filtering the gas. Gas filtration was found to have no effect on the acid dewpoint.

Corrosion of Type 309 Steel in Furnace Flue Gas

R. D. MERRICK: 'High-Temperature Furnace Corrosion of Type 309 Alloy Steel.'

Corrosion, 1960, vol. 16, Nov., pp. 578t–80t.

A.I.S.I. Type 309 25-12 chromium-nickel steel is noted for its resistance to corrosion by high-temperature flue gases, and its performance in this respect has been reported to be superior to that of such higher-nickel materials as Type 310 25-20 chromium-nickel steel and the nickel-chromium-base alloy 'Incoloy'. Recently, however, Type 309 steel has suffered severe corrosion when exposed to flue gas in high-temperature refinery furnaces, although, in the same furnace, the corrosion-resistance of higher-nickel materials has been adequate. Although the exact cause of this high rate of corrosion has not been established, the present paper was written in the hope that discussion of the circumstances surrounding the failures would induce further study

of the performance of these materials in such environments.

The furnaces in question were of radiant type, with a single row of horizontal tubes located in the centre of the firebox. These tubes were supported, at six-foot intervals, by cast vertical 'H' beams, with the tubes passing through the web of the beam. About 100 re-radiating gas burners were located on each side of the box, approximately three feet from the tubes. The design temperatures for the tubes and supports ranged from 1600° to 2100°F. (870°-1150°C.), and, since the flue gas was expected to contain a high concentration of hydrogen sulphide, Type 309 steel was selected as the material of construction. (The high-nickel alloys were rejected because of the high corrosion rates anticipated in the presence of the high-sulphur flue gas.) After seven months' operation severe corrosion had occurred in both the tubes and supports.

The corrosion failures are discussed by the author in relation to the nature of the attack, the firebox conditions, the results of chemical analysis of the corrosion products, and the data obtained from corrosion tests, under firebox conditions, on 'Incoloy', Incoloy 804, and Type 304, Type 309 and Type 310 (18-8, 25-12 and 25-20) chromium-nickel stainless steels. An examination of the firebox conditions showed that the hydrogen-sulphide content of the flue gas ranged from 0·2 to 6·8 mol. per cent.

In the three-month furnace tests on the five nickel-containing materials, the 18-8 sample was destroyed by oxidation. The 25-20 steel sample exhibited considerably greater resistance than the 25-12 specimen (corrosion rates were 8·9 and 84·5 mils/year, respectively), and the resistance of the higher-nickel alloys was similarly satisfactory. The sulphur content of the gas was nil during this test period, but tests in a second furnace operating at a flue-gas sulphur content of about 2 mol. per cent. confirmed the superiority of the higher-nickel alloys.

The author's assessment of the data available to date leads him to the conclusion that the corrosion rate of Type 309 steel increases as the flue gas approaches reducing conditions (i.e., the corrosion rate rises with decrease in the CO_2/CO ratio of the flue gas: at ratios less than about 2·0, the material is considered no longer suitable for long-term use). The presence of sulphur in the flue gas did not appear to affect the rate of corrosion. It is suggested that the rate of attack was probably increased by the presence of materials foreign to the firebox (suspicion falling on titania introduced as a result of painting the furnaces).

In discussing the materials tested the author makes the following statement:

'The materials tests conducted in these furnaces subsequent to the corrosion failures pointed out the inadequacy of the 25Cr-12Ni alloy. In all tests conducted, the superiority of the higher-nickel alloys was evident. With 25 per cent. chromium present in the alloy, a minimum of 20 per cent. nickel was required for adequate corrosion-resistance. With higher nickel contents, the chromium may be reduced without a sacrifice in resistance.'

Fireside Corrosion of Superheater Tubing in Coal-Fired Boilers

J. JONAKIN, G. A. RICE and J. T. REESE: 'Fireside Corrosion of Superheater and Reheater Tubing.' *Amer. Soc. Mechanical Engineers*, 1959, *Paper 59-FU-5*; 8 pp.

In the production of electricity there is a constant demand to reduce fuel costs by increasing station thermal efficiencies. The most common method of achieving this aim is to increase steam temperatures, and, as a result of the development of materials with the necessary mechanical properties to withstand higher steam temperatures and pressures, temperatures of 1000°-1050°F. (540°-565°C.) are nowadays quite common. The products of combustion from coal containing high amounts of sulphur and alkalis are associated with the formation of low-melting ashes which, in the region of 1800°F. (980°C.), can form bonded deposits and result in corrosion. To obtain steam temperatures of 1050°F. (565°C.), superheater and reheater tubing is placed in the boiler-gas passes [where gas temperatures range from 1400°-2200°F. (760°-1205°C.)], and consequently there is risk of fireside corrosion. The Joppa Steam Electric Station incorporates six boilers and turbines (with the necessary auxiliary equipment), and burns approximately 3,149,000 tons of bituminous coals per year. The fireside corrosion which occurred in superheater and reheater tubing of this station forms the subject of the present paper.

The paper is in three main sections. In the first, details are given of attempts to reduce, or eliminate, corrosion by the installation of shields of Type 310 stainless steel designed to fit over tubing on the leading side. The second section is concerned with the development of a corrosion probe, which was subsequently used to determine the corrosion-resistance of materials under field conditions, and also to study methods of reducing metal wastage: details are given of tests in which the probe was used to determine the corrosion rates exhibited by various materials of construction (including Type 321 18-8-Ti austenitic stainless steel). Since it was found that wastage of Type 321 stainless steel occurred only under deposits, a study was initiated to determine the mechanism by which the constituents of coal ash adhere to the tubes and by which deposits cause corrosion. The results of this study are discussed in the third and last section of the paper.

Stainless-steel shields were found to provide a satisfactory temporary method of protecting superheater and reheater tubes. On the basis of data obtained in the other phases of the investigation, it is concluded that deposits form on tubes initially by the action of sticky fly-ash particles which adhere to the metal and form a porous sintered deposit. Various constituents of the coal ash were found to deposit selectively on the superheater and reheater tubes in the Joppa units, and this phenomenon resulted in the formation of deposits at gas temperatures considerably below the fusion temperature of the total coal ash. Sulphurous gases from the flue gas combined with the tube deposits to form complex alkali iron sulphates (which are molten in the temperature

range of maximum metal wastage), and the formation of these strongly oxidizing salts in the molten condition is considered a possible cause of the corrosion of the superheater and reheater tubing.

Corrosion of Superheaters and Reheaters in Coal-Fired Boilers

W. NELSON and C. CAIN: 'Corrosion of Superheaters and Reheaters of Pulverized-Coal-Fired Boilers.'

Amer. Soc. Mechanical Engineers, Paper 59-*A*-89, 1959; 8 pp.

The work reported by the authors originated in the discovery that the reheater and finishing superheater tubes in a 1055°/1005°F. (568°/540°C.) boiler fired by pulverized coal exhibited considerable external corrosion. Although in operation only two years, some reheater tubes fabricated from A.I.S.I. Type 321 18-8-Ti stainless steel were found to have been reduced to about 50 per cent. of their original 0·125-in. (3·125-mm.) thickness, a penetration rate of 0·032 in./yr. (0·8 mm./yr.). Corrosion was spread fairly evenly from left to right, and top to bottom, in both reheater and superheater. To determine the nature and extent of the corrosion problem, an inspection was made of 26 pulverized-coal-fired boilers in various parts of the U.S.A., but advanced corrosion was observed in only a few units. The findings of this inspection led to the establishment of a research programme, which, designed to determine the cause and prevention of this type of accelerated wastage, involved extensive study of the corrosion mechanism in relation to specimens of Type 321 and SA 213 T22 (2¼-1 chromium-molybdenum) steels. The results of the study are presented in this paper.

The work carried out is reported in sections concerned with: laboratory experiments to determine corrosion rates in flue gas and air; chemical analysis of deposits obtained from field inspections; X-ray-diffraction studies; the thermal behaviour of deposits; migration of complex sulphates; nature of corrosion by complex sulphates; corrosion of T22 and Type 321 steels by complex sulphates; and remedial measures.

The authors' summary of the conclusions drawn from the investigation is quoted below:

'The present work has shown that molten complex iron and/or aluminium alkali sulfates, formed in fireside deposits of boilers having steam temperatures above about 950°F., are responsible for corrosion of superheater and reheater tubes. This corrosion is a chemical reaction in which the tube metal reacts with molten sulfates to give iron oxide and sulfide. It starts at a temperature below the oxidation (scaling) temperature limit for alloys used in these sections of a boiler. Gas-phase scaling-temperature limits cannot therefore be used to judge the suitability of a given alloy for service in an area subject to liquid-phase corrosion by complex sulfates of an ash deposit. For instance, the 321 stainless-steel alloy encounters rapid liquid-phase attack at about 1000°F. (540°C.), whereas its resistance to corrosion by flue gas alone is satisfactory at higher than 1450°F. (800°C.). Liquid-phase corrosion is bracketed between melting and maximum synthesis temperatures of the complex sulfates present on the tube surface under the deposits. Studies to find more corrosion-resistant alloys, or less corrosion-producing coals, seem promising fields for future effort.

Shielding lead tubes in the deposit-forming areas of the finishing reheater and superheater, where skin-metal temperatures are between 900° and 1400°F. (480° and 760°C.), is the best practical means to date for preventing accelerated liquid-phase corrosion in pulverized-coal-fired units.'

Resistance of Nickel-containing Nuclear-Power-Plant Tubing Materials to Corrosion by Boiler Sludge

E. HOWELLS, T. A. MCNARY and D. E. WHITE: 'Corrosion of Nuclear-Power-Plant Tube Materials by Boiler Sludge.'

Corrosion, 1960, vol. 16, Nov., pp. 571t-6t; disc., pp. 576t-7t.

The sludge commonly encountered in the steam generators of power plants usually consists of iron oxides and metallic copper, with smaller amounts of copper oxides and other impurities from the secondary (feedwater) system. In conventional power boilers of water-tube type, this sludge can be allowed to accumulate in a chamber, from which it is removed by means of a bottom blow-down connexion. In the steam generators used in nuclear-power plants, however, the configuration of the units renders sludge removal considerably more difficult. Steam generators for pressurized-water nuclear-power plants are predominantly of the vertical-shell and U-tube design (in which boiling occurs outside the tubes). The tubing is very closely spaced and provides a potential sludge trap, especially at the surface of the horizontal tube sheet, and bottom blow-down lines are generally ineffective in removing sludge.

The corrosive effect of sludge accumulations is relatively unknown. Since this factor is of significance in nuclear-power steam generators (due to the importance of plant integrity and the difficulty that would be encountered in removing sludge from the surface), the programme described by the authors was initiated to determine the resistance of representative tube materials to corrosion by boiler sludge under steaming conditions.

The test specimens used in the study were heat-exchanger models of the same general configuration as the steam generators currently used in nuclear-power plants, and the general test conditions were designed to simulate those obtaining in the operation of pressurized-water plants. At the start of each test, a heavy layer of actual power-boiler sludge was placed on the surface of the horizontal tube sheet exposed to the secondary system. During testing the models were operated as steam generators for periods ranging from one month to one year. At the end of each test, the unit was examined metallographically to determine the location, nature and extent of corrosion. The secondary systems of all the heat exchangers except one (which was designed for higher temperatures) were operated at a temperature of

480°–490°F. (250°–255°C.) and a pressure of 600 p.s.i.g.

Six materials were evaluated: 'Inconel', 'Monel', A.I.S.I. Type 347 18–11–Nb stainless steel, Type 304 19–10 stainless steel, 'Croloy 16–1', and carbon steel. Full details are given of the test conditions and apparatus employed.

The results of the metallographic study revealed that the presence of boiler sludge can cause accelerated corrosion of tubing materials. 'Inconel' exhibited little evidence of corrosion, and possessed, even in the presence of chloride ion and oxygen, the highest corrosion-resistance of the materials tested. Type 347 stainless steel, which was next in order of corrosion-resistance, showed signs of surface etching and some random pitting up to a depth of 2½ mils (caution is, however, advised in any extrapolation of these results to very long operating periods). 'Croloy 16–1' was superior in performance to 'Monel' and carbon steel, but suffered more general pitting (to a depth of 2½ mils) than Type 347 steel. 'Monel' was more severely corroded, and preferential attack (up to a depth of 11 mils) occurred at crevice openings. Carbon steel, rated the least resistant of the materials evaluated, suffered the severest attack, and its surface was severely roughened.

On the basis of the data presented, the authors propose that, under the given environmental conditions (which include traces of free chlorine as oxidizing agent), corrosive attack is initiated at the highly active structure-sensitive sites (dislocations, sub-boundaries and grain-boundaries). Due to their less noble potentials, chromium and iron, and in particular chromium, are preferentially leached out of the alloy by galvanic action, thus producing composition gradients in the alloy. These gradients become the driving force for diffusion. Chromium in particular migrates out, and since diffusion proceeds by a vacancy mechanism, and since (due to electrochemical factors) chromium, arriving at the surface of the specimen, is again dissolved in preference to the other alloying constituents, a vacancy concentration occurs in the metal. At the test temperature (800°C.), lattice-vacancy mobilities are high, and coalescence of these by diffusion leads to the formation of micro, and eventually macro, voids. The blistering and peeling-off of layers of this sponge, which aggravates this type of corrosion, appears then to be a consequence of this pore coalescence and the different coefficients of expansion of the 'Inconel' and the attacked layer.

Selective Corrosion of 'Inconel'

R. BAKISH and F. KERN: 'Selective Corrosion of 'Inconel'.'

Corrosion, 1960, vol. 16, Nov., pp. 533t–4t.

In a recent investigation of the mechanism underlying the reported selective corrosion of 'Inconel', sheet, rod and tube specimens were immersed in a fused-salt bath comprising 20 per cent. K_2TaF_7 and 80 per cent. of a 1/1 molar mixture of KCl/NaCl with traces of Cl_2. The tests were carried out at 800°C. for times up to 50 days, the bath being maintained under an inert nitrogen atmosphere throughout. The specimens were of the following nominal composition: nickel 75·4, chromium 15·03, iron 7·2, carbon 0·08, per cent. Under these conditions, a superficial layer of porous sponge-like material was found to form, and analysis of the corroded surface revealed that chromium and iron had been preferentially leached out.

Manly *et al.* (*Second International Conference on Peaceful Uses of Atomic Energy*, 1958, *Preprint No.* 1990) tended to interpret this type of corrosion almost entirely in terms of the Kirkendall effect. While the authors of the present article were in agreement with Manly, they felt that electrochemical factors would also play an important rôle in the initiation of the corrosion process and in the constant removal of chromium in preference to the other alloying constituents. To confirm this assumption, the potentials of the alloying elements were determined under the prevailing conditions by measuring the e.m.f. of cells of the type $Me°/Me^{x+}// (Cl^-/Cl_2)$ graphite, with Me=Ni,Fe,Cr, in an equimolecular sodium-chloride/potassium-chloride melt containing 10 per cent. potassium fluoride.

Stress-Corrosion Cracking of High-Strength Oil-Well Tubing

R. S. LADLEY: 'Stress-Corrosion Cracking of High-Strength Oil-Country Tubular Goods.'

Corrosion, 1960, vol. 16, Nov., pp. 539t–42t; disc. p. 542t.

Although advances in the fabrication and handling of oil-country tubular goods have resulted in improved mechanical properties, catastrophic failures due to stress-corrosion cracking have steadily increased. In the present paper, the author reviews the factors involved in cases of failure in tubing and casing in 'N-80' steel, and in tubing in A.I.S.I. 4340 nickel-chromium-molybdenum low-alloy, 9 per cent. nickel, and 9 per cent. chromium steels.

The problem of stress corrosion is discussed in relation to (1) the measures which are currently employed to minimize susceptibility to cracking, and (2) the approaches which might be expected to result in the elimination of failure in high-strength steel and, hence, in the application of tubing in such steel to optimum effect in oil- and gas-well environments.

Identification of Chi and Sigma Phases in Stainless Steel

L. S. BIRKS, J. M. SIOMKAJLO and P. K. KOH: 'Identification of Chi and Sigma Phases in Stainless Steel with the Electron-Probe Microanalyzer.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Oct., pp. 806–9.

Long-time exposure of stainless steels to temperatures in the region of 1600°F. (870°C.) may cause precipitation of the brittle σ or χ phases, with subsequent adverse effects on properties. Because of their

similarity, identification of these phases by microscopy is often not feasible, and X-ray diffraction *in situ* is unsuitable because of matrix interference. Wet chemical analysis or X-ray diffraction of extracted residues are time-consuming, and give only an average composition when both χ and σ occur together in a specimen. While it has been pointed out that the electron-probe microanalyzer is well suited to the measurement of small precipitates *in situ*, it has been estimated that the smallest area for which the absolute composition may be given is 3–4μ. The σ and χ precipitates that occur in practice are very seldom as large as 3–4μ, and the question therefore arises as to the feasibility of identifying them by this technique. The investigation now reported was undertaken with the aim of answering this question.

Specimens of A.I.S.I. Type 317 steel and 'Timken alloy' (see table below) were heat-treated to produce χ and/or σ precipitates ranging in size from several microns to less than one micron, and were then etched and examined in the electron probe (set for simultaneous measurement of chromium, molybdenum, nickel and iron).

Steel	Cr %	Mo %	Ni %	Mn %	Fe %
Type 317	18·10	3·20	13·53	1·5	63
'Timken Alloy'	16·34	5·90	15·24	7·4	55

X-ray intensities were calibrated in terms of percentage composition, and the results were checked against wet chemical analysis.

The data obtained demonstrate that, although particles in the region of 1μ in size are too small to yield the absolute percentage composition, the estimated chromium/molybdenum ratio may be used to identify the two phases *in situ* with better than 95 per cent. confidence, even when the size of the precipitate is smaller than that of the electron beam. The chromium/molybdenum ratio from X-ray data is about twice as large for σ phase as for χ phase, and this ratio is in good relative agreement with similar ratios derived from wet chemical analysis of extracted residues.

Although the chromium/molybdenum ratio measured in Type 317 steel remains about the same, it changes appreciably when there is a radical change in composition (such as the addition of 10 per cent. tungsten or the substitution of cobalt- or nickel-base alloys for iron-base materials). The fact that individual precipitates in a specimen may be identified as χ or σ phase is regarded as a significant advantage of the electron probe: even if both phases occur in one steel, it may be only the precipitates at particular locations (such as grain boundaries) which control the mechanical properties, and, by means of the electron probe, it is possible to distinguish between particles at a particular location.

Microchemical Separation by the Ring-Oven Technique

See abstract on p. 10.

Mould for Simultaneous Sampling of Metals for Spectrographic and Chemical Analysis

See abstract on p. 12.

Nickel-Alloy Wire for Special Applications

K. P. BROWN: 'The New Nickel Alloys in Wire for Special Applications.'

Wire and Wire Products, 1960, vol. 35, Aug., pp. 978–9, 981, 1052–3.

In this article the author refers to the increasing use which is being made of nickel-base-alloy wire in applications demanding corrosion-resistance and/or heat-resistance, and then, selecting 'Inconel X', 'Inconel 700', 'Inconel 702', 'Inconel 718' and 'Ni-O-Nel' as representative, goes on to review the salient characteristics of alloys of this class and the applications for which, in the form of wire or components fabricated from wire, they have been found suitable. The article ends with a brief *résumé* of the procedures involved in the production of such wire.

Cold Heading of Nickel-containing Materials

T. B. SMITH: 'Design for Cold Heading.'

Wire and Wire Products, 1960, vol. 35, Sept., pp.1113–16, 1118–20, 1184–5.

Cold heading is extensively used in the production of nails, rivets, screw blanks and other types of fastener. In this review attention is drawn to the basic principles involved in the process, the materials commonly subjected to cold heading, the factors which must be taken into account in cold heading such materials, and the design of parts produced by the technique.

The author first outlines the procedures generally used in cold heading with solid-die and open-die machines. He then compares the scope, advantages and limitations of cold heading with those of hot heading and screw machining, and comments briefly on cost considerations.

The range of materials which can be cold headed is extremely wide. Carbon steels and stainless steels are cold headed in great quantity, and most non-ferrous metals and alloys can be successfully upset. Materials typical of those commonly cold headed are discussed (from the point of view of their response to cold heading, and of the fastener applications for which they have been found suitable) in sections concerned with: carbon steels, low-alloy steels, straight-chromium and chromium-nickel stainless steels, copper and copper-base alloys, aluminium and aluminium-base alloys, and nickel and nickel-base alloys (commercial nickel, 'Monel' and 'Inconel').

In subsequent sections consideration is given to: the influence of cold heading on the properties of the material; the sizes and shapes obtainable by cold heading; tolerances; finish; and the factors involved in the design of cold-headed parts.

ANALYSIS

Separation of Radiocobalt from Nickel

See abstract on p. 4.

Determination of Zinc in Nickel

See abstract on p. 4.

Microchemical Separation by the Ring-Oven Technique

See abstract on p. 10.

Mould for Simultaneous Sampling of Metals for Spectrographic and Chemical Analysis

See abstract on p. 12.

PATENTS

Extraction of Nickel and Magnesium from Ores

The patent relates to a treatment for conversion of hydrated silicates of nickel and magnesium (in the form of ore, concentrate or by-products) to water-soluble salts of nickel and of magnesium. The hydrated silicate, e.g., garnierite, is (in the absence of any other compound reactive under the conditions) reacted with sulphur-trioxide gas, or with an externally formed catalytically activated gaseous mixture of oxides of sulphur and an oxygen-containing gas (preferably air), in either case at 300°-900°C.

The procedure results in the decomposition of the hydrated silicates to form nickel and magnesium sulphates. Under proper conditions, almost quantitative extraction of nickel and magnesium is obtained.

DEPARTMENT OF MINES, PROVINCE OF QUEBEC (inventors, M. ARCHAMBAULT, C. A. OLIVIER and J. U. M. MACEWAN). *Brit. Pat.* 849,364.

Reduction of Nickel Oxide

In the reduction of nickel oxide to metallic nickel in the presence of a reducing gas in a rotary kiln (an intermediate stage in the production of nickel carbonyl), the metal powder so produced has tended to adhere, probably by an alloying effect, to the wall of the kiln (which is commonly lined with steel or cast iron). According to the present invention, this tendency is eliminated by lining the kiln with a metal or alloy which forms a completely continuous oxide film that is irreducible at the operating temperature: aluminium or a sintered mixture of aluminium and alumina are specifically claimed.

MOND NICKEL COMPANY, LTD. (inventors, D. H. WEST, S. C. TOWNSHEND AND A. B. SIMPSON). *Brit. Pat.* 854,461.

Diamond Synthesis in the Presence of a Nickel Catalyst

A carbonaceous material (preferably graphite) is converted to diamond, at elevated temperatures and a pressure of at least 50,000 atmospheres, in the presence of an alloy of a catalyst selected from the elements iron, cobalt, nickel, ruthenium, rhodium, palladium, osmium, iridium, platinum, chromium, tantalum and manganese. The preferred catalyst is an alloy of nickel and chromium, nickel and manganese, nickel and iron, nickel and copper, or iron and manganese.

H. M. STRONG, assignor to GENERAL ELECTRIC COMPANY. *U.S. Pat.* 2,947,609.

Colouring Substances for Hectographic Printing

The transfer sheets for hectographic printing covered by the patent consist of a backing sheet, the coloured substance on one side of which is soluble in the duplicating liquid. The inclusion in the molecule of the coloured substance of at least one chemically bound metallic or non-metallic element having an atomic weight of at least 52 is stated to permit the production of copies having light fastness greatly superior to that obtainable with transfer sheets with ordinary basic dyestuffs.

Among the colouring substances claimed, $Ni(HC_4H_6N_2O_2)_2$ gives a red copy, $Ni(C_6H_5O_3S)_2$ gives a green copy, and NiI_2 gives a black copy.

G. E. F. RUBEN *Brit. Pat.* 847,398.

Improved Hair Bleach

A composition for bleaching human hair consists of a paste comprising a mixture of aqueous hydrogen peroxide and a powder containing magnesium oxide and/or magnesium carbonate and between 0·01 and 10 wt. per cent. of a finely-divided phthalocyanine of copper, cobalt, nickel or zinc (or their derivatives substituted in the benzene nuclei by sulphonic groups or chlorine atoms). The presence of the metal phthalocyanines results, due to catalytic action, in a progressive and homogeneous bleaching effect, and avoids the occurrence of yellow and red tinges in the treated hair, minimizes formation of oxygen bubbles and hair damage, and imparts a blue coloration to the paste or cream.

LAWRENCE RICHARD BRUCE, INC. (inventor, B. LUSTIG). *Brit. Pat.* 852,777.

Frit for Porcelain Enamelling Aluminium

Crack- and acid-resistant porcelain-enamel coatings particularly suitable for use on aluminium or aluminium-alloy components (e.g., kitchen ware) are formed from a frit containing SiO_2 25-50, TiO_2 10-25, at least one TiO_2-dissolving oxide (selected from a given group) 10 max., Li_2O 5-15, K_2O 2-13, Na_2O 15-25, B_2O_3 0·5-8, P_2O_5 0-5, mol. per cent. The ratios in which the constituent oxides are present are given.

The frit should preferably include up to 50 mol. per cent. of adherence-promoting oxide selected from CuO, NiO, CoO, Sb_2O_3 (1 per cent. max.), PbO and Bi_2O_3.

MINNESOTA MINING AND MANUFACTURING COMPANY
Brit. Pat. 847,225.

Primer Coating for Application of Fluorinated Olefin Polymers

Fluorinated olefin polymers (e.g., polymers of chlorotrifluorethylene) exhibit attractive properties, such as low permeability, high abrasion-resistance, high tensile strength and impact strength, and excellent resistance to corrosive chemicals. Their use as coatings is limited by their adhesive characteristics, which, particularly with respect to metallic materials, are poor, and recourse must therefore be had to primer coatings which facilitate adhesion. According to the present invention, a primer coating suitable for such purposes comprises a volatile dispersing vehicle, a normally solid polymer of a perfluorhaloolefin containing 2 or 3 carbon atoms, and (in the proportion of 5–60 parts by weight per 100 parts by weight of the solid polymer) an oxide of antimony, manganese, nickel or cobalt. Such coatings, which are cured at 350°–600°F., may, it is stated, be applied to, *inter alia*, steel, 'Inconel', and 'Monel'.

MINNESOTA MINING AND MANUFACTURING COMPANY.
Brit. Pat. 848,729.

Insoluble Anodes for Use in Nickel Plating

An insoluble anode, for use in a halide-free nickel-plating solution (preferably of all-sulphate type), and stated to overcome the disadvantages associated with lead or wrought-nickel insoluble anodes (e.g., contamination of the solution, undesirably high current efficiency), consists of a metal or alloy core electroplated with an adherent 0·125–2·5 mm. coating of nickel free from depolarizing constituents. The core of the anode is preferably made from wrought nickel.

The procedures employed in the fabrication of the anodes covered are outlined in the preamble of the patent.

MOND NICKEL COMPANY, LTD. *Brit. Pat.* 852,931.

Nickel-Plating Solutions with Enhanced Levelling Properties

Additions of the following (in the amounts stated) are claimed to confer enhanced levelling properties on an aqueous acidic nickel-plating solution (e.g., a Watts solution): xanthone (0·001 g./L. to saturation), xanthone-2,7-disulphonic acid (0·01–2 g./L.). xanthone-2,7-disulphonamide (0·005 g./L. to saturation), or xanthone-2,7-disulphonacetamide (0·02 g./L. to saturation).

WILMOT-BREEDON, LTD. (inventor, U. F. MARX).
Brit. Pat. 852,030.

Deposition of Solderable Alloy Coatings on Non-Metallic Materials

Non-metallic materials, such as porcelain, glass and carbon, are rendered solderable by deposition of an adherent coating of an alloy (1) comprising at least two of the elements iron, nickel and cobalt (and containing, for example, 10–70 per cent. nickel) and (2) having a similar coefficient of thermal expansion to that of the substrate material.

The alloy is preferably deposited by thermolysis (in the presence of suitable carrier or protective gases) of the appropriate metal carbonyls (e.g., nickel carbonyl and iron pentacarbonyl) at concentrations ensuring formation of an alloy of the required composition. In a preferred application, a solderable coating of a nickel-iron alloy is deposited on to a rod-shaped carbon resistance element.

SIEMENS AND HALSKE A.G.
(inventors, P. MILTENBERGER AND G. LOCHMANN).
German Pat. 1,089,613

Deposition of Nickel-Boron Alloys

Nickel-boron or cobalt-boron alloys are deposited from a solution containing a borate of a secondary or tertiary amine and a soluble nickel or cobalt salt. The borate radical is present at a concentration of 0·1–3 wt. per cent., the metallic-ion concentration lies in the range 0·02–6 wt. per cent., and the pH of the solution is maintained at 2–6·5 by addition of a weak non-oxidizing acid (e.g., boric acid). The alloys covered contain 4–10 per cent. of boron.

Procedures suitable for plating, *inter alia*, nickel 'Inconel', 'Monel' and cupro-nickels are described.

GALLERY CHEMICAL COMPANY
(inventor, R. M. HOKE). *French Pat.* 1,232,067.

Nickel-boron, cobalt-boron or iron-boron alloys are deposited from a solution consisting essentially of an ionizable borohydride (preferably sodium borohydride), soluble salts of iron, cobalt or nickel, and ammonia. The borohydride-ion concentration lies in the range 0·01–0·2 wt. per cent., the metallic-ion concentration in the range 0·02–5 wt. per cent., and that of the ammonia in the range 1·5–25 wt. per cent. The pH is maintained in the range 10–12 and the solution is operated at 25°–40°C.

GALLERY CHEMICAL COMPANY
(inventor, R. M. HOKE). *French Pat.* 1,232,068.

Production of Nickel-Phosphorus Powder

Nickel-phosphorus-alloy powder is produced by electrolysis, at a temperature of at least 270°C., of a buffered aqueous acidic solution having a pH of 1·7–4·5 and containing 0·6–8 g./L. of nickel, 3–14 g./L. of phosphorus (in the form of phosphite or hypophosphite ions), and ions of one or more of the following (to a total amount equivalent to 2–7·5 g./L. of sodium ions): sodium, potassium, magnesium or ammonium. Use is made of a combination of soluble nickel and insoluble anodes, and the cathodic current density lies in the range 1·1–21·5 amp./dm.^{2} (the

current density is correlated with the nickel concentration in an accompanying drawing). The solution is preferably buffered with 20–40 g./L. of boric acid.

The sodium, potassium, magnesium or ammonium ions serve to promote the formation of a powdery or friable deposit, and use of both soluble and insoluble anodes helps the buffering agent to control the pH in the desired range.

The nickel-phosphorus powder produced in accordance with the invention is stated to be suitable as a brazing material, and should preferably contain 10–12 per cent. of phosphorus.

MOND NICKEL COMPANY, LTD. *Brit. Pat.* 848,390.

Stripping of Nickel-Phosphorus Coatings

Nickel-phosphorous coatings are stripped from a steel component, without attack on the substrate, by immersing the component in a stripping bath containing fuming nitric acid 41·5–68·4, hydrofluoric acid 2·9–24·5, mole per cent., remainder water. The temperature of the solution should not be higher than 150°F. (65°C.).

B. J. SHERWOOD AND W. R. HOYT, assignors to CHEMPLATE CORPORATION. *U.S. Pat.* 2,954,289.

Stripping of Nickel Deposits from Copper-base Substrates

The invention is based on the discovery that a hot aqueous solution of a disulphide dicarboxylic acid will readily dissolve nickel, but has little or no effect on copper, copper-base alloys or brass. Accordingly, nickel deposits are removed from such substrates by treatment, at 60°C., in an aqueous solution of, preferably, 3–40 per cent. w/v of dithiodihydracrylic acid, dithiodilactic acid, or dithiodiglycollic acid. Dissolution of the nickel is facilitated when a mineral acid and an oxidizing agent are included in the solution.

ROBINSON BROTHERS, LTD. (inventor, I. A. M. FORD). *Brit. Pat.* 850,123.

Nickel/Chromium/Nickel Coatings with Improved Resistance to Atmospheric Corrosion

The invention is based on the finding that, compared with a single nickel deposit of similar thickness, a composite coating comprising one or more intermediate layers of chromium interposed between layers of nickel exhibits superior resistance to atmospheric corrosion, protects the basis metal more effectively, and retains its pleasing appearance longer in service. Accordingly, the patent claims a metallic article plated with a composite coating comprising alternate layers of nickel (each 2·5–50μ thick) and of chromium (each 0·025–2·5μ thick), there being at least two layers of nickel, one of which is the foundation layer. The minimum total thickness of the composite coating is 6·25μ, and the outer main layer is preferably of nickel (finished with a final decorative coating of chromium).

Methods of producing the coatings covered are referred to in the preamble, which also includes data typifying corrosion-resistance.

MOND NICKEL COMPANY, LTD. *Brit. Pat.* 852,673.

Composite Coating Exhibiting Improved Atmospheric Corrosion-Resistance

The invention is based on the finding that, compared with a single nickel layer of similar thickness, a composite coating, comprising one or more intermediate layers of cobalt, tin, palladium or a cobalt-tungsten or cobalt-nickel alloy interposed between layers of nickel, exhibits higher atmospheric corrosion-resistance, protects the basis metal more effectively, and retains a pleasing surface appearance longer in service. According to the claims of the patent, the layers of nickel are 2·5–50μ thick, and those of the cobalt, tin, palladium or the cobalt-tungsten or cobalt-nickel alloys (which contain up to 90 per cent. nickel and 20 per cent. tungsten) are 0·25–7·5μ thick. The layers are applied alternately to form a composite at least 6·25μ thick, the foundation and outermost layers of which consist of nickel. The various layers are preferably applied by electrodeposition, but may be deposited by chemical plating or thermal decomposition of metal carbonyls.

The improvement in corrosion-resistance is believed to be associated with the use, as the intermediate layer of the composite, of a metal having a definite galvanic relationship to nickel.

MOND NICKEL COMPANY, LTD. *Brit. Pat.* 853,236.

Production of Anisotropic Permanent Magnets

The patent covers a method of producing anisotropic permanent magnets containing cobalt 28–42, nickel 10–20, aluminium 6–10, copper 2–8, titanium 4–10, per cent., remainder iron. The magnet is subjected to a magnetic field while being cooled from 1210°C. to 600°C. in >1 minute to <10 minutes, heated from 600°C. to the range 10°–70C.° below the Curie temperature, and maintained in that range, at constant temperature ($\pm$10C.°), for 2–30 minutes.

The effect of cooling rate on the $BH_{max.}$ of various magnet compositions is illustrated in the preamble of the patent.

PHILIPS ELECTRICAL INDUSTRIES, LTD.

	Brit. Pat.	852,249.
Similar to S. African	,,	123/57.
,, ,,	*Canad.* ,,	575,039.
,, ,,	*U.S.* ,,	2,933,427.

Nickel-containing Ferrites Exhibiting Constricted Hysteresis Loops

The three patents referred to over-page cover ferromagnetic ferrites containing additions of 0·1–5 wt. per cent. of cobalt oxide and exhibiting constricted hysteresis loops. The appropriate oxides are mixed, ground, screened, compacted, sintered at a temperature higher than 1000°C., and (to produce the constricted hysteresis loop) slowly cooled to room

temperature over a period of at least 12 hours, or, in the case of the first two patents, rapidly cooled and then reheated to about 700°C. and slowly cooled to room temperature over a period of at least 12 hours, or, in the case of British Patent 849,464, rapidly cooled to about 700°C. and slowly cooled to room temperature over a period of at least 12 hours.

A cobalt-oxide addition of 0·35–1·5 wt. per cent. is preferred, and the ferrites which react to the cobalt-oxide addition with a constricted hysteresis loop are defined in ternary diagrams included in the respective patents.

British Patent 489,217 covers nickel, manganese, nickel-zinc, manganese-zinc, nickel-cadmium and manganese-cadmium ferrites.

British Patent 489,218 covers manganese-copper, manganese-magnesium, magnesium-zinc and magnesium-cadmium ferrites.

British Patent 849,464 covers manganese-nickel, nickel-copper and nickel-magnesium ferrites.

STEATIT-MAGNESIA A.G. *Brit. Pats.* 849,217· 849,218· 849,464·

Nickel-base High-Temperature Alloys

The alloys covered by the patent are stated to exhibit high creep strength at elevated temperatures (e.g., in the range 800°–1100°C.) and to be particularly suitable for casting (and, indeed, rupture strength is optimum when they are vacuum-cast). A rupture strength of 4–8 tons/in.² (9000–18,000 p.s.i.: 6·5–13 kg./mm.²), based on a life of 15–100 hours in the range 950°–1050°C., is given as typical. Castings are normally used without subsequent heat-treatment.

The following limits of composition are claimed: chromium 5–30, aluminium >5–10, tungsten 2–10, molybdenum 3–15 (tungsten + molybdenum >5), boron 0·1–2, carbon 0·05–0·5, manganese 0·05–2, silicon 0·05–2, cobalt 0–30, iron 0–20, niobium >1–6, wt. per cent., remainder (and not less than 50 per cent.) nickel. The alloys may also contain one or more of the following: titanium 5 max., tantalum 6 max., beryllium 2 max., copper 5 max., vanadium 5 max., wt. per cent.

BIRMINGHAM SMALL ARMS CORPORATION (inventors, G. T. HARRIS AND H. C. CHILD).
Brit. Pat. 853,103.
Similar to French „ 1,160,309.

Nickel-Chromium-Cobalt High-Temperature Alloys

The alloys covered are for use, as castings or forgings, in applications involving exposure to stress in the temperature range 600°–1000°C. They contain cobalt 10–35, chromium 5–<13, aluminium >2–10, molybdenum 1–10, titanium 1–3, iron <5, manganese 0·1–1, silicon 0·1–1, carbon >0·15–0·5, tungsten 2–15 and/or boron 0·001–0·5, per cent., nickel remainder. One or more of the elements niobium, tantalum and vanadium may also be present (up to a total content of 3–12 per cent.).

WILLIAM JESSOP AND SONS, LTD. (inventors, G. T. HARRIS and H. C. CHILD).
Brit. Pat. 853,468.
Addition to „ „ 783,955.

Vacuum-Cast High-Temperature Nickel-base Alloys

Vacuum-cast nickel-base alloys, suitable for use in applications involving exposure to load at elevated temperatures, contain chromium 14–17, molybdenum 4–7, iron 4–6, aluminium 3·6–5, titanium 3–4, carbon 0·08 max., boron 0·05–0·1, wt. per cent., remainder nickel. Manganese and silicon contents are each restricted to 0·1 max. per cent.

The rupture life is increased by subjecting the as-cast alloy to heat-treatment for 1 hour in the range 1135°–1205°C., and air cooling. A rupture life of 200 hours at 1010°C. under a load of 10·5 kg./mm.² can, it is stated, be attained by such treatment.

GENERAL ELECTRIC COMPANY (inventors, E. L. DUNN, J. E. WILSON, M. E. CIESLICKI and J. B. MOORE).
French Pat. 1,232,253.

Iron-Nickel-Chromium-Molybdenum Heat-Resisting Alloy

The aim of the invention is the provision of a heat-resisting alloy 'less expensive than, but equal, or superior to, prior alloys, particularly in such respects as resistance to corrosive gases at high temperatures, strength and resistance to deformation at high temperatures, length of life and rate of creep'. Steels falling within the following composition range are claimed to satisfy this aim: carbon 0·45–0·55, manganese 1–4, silicon 1–2·5, sulphur 0·4 max., phosphorus 0·4 max., nickel 34–37, chromium 23–27, molybdenum 1–2, aluminium 0·05–0·4, nitrogen 0·15–0·4, boron 0·001–0·04, per cent., remainder iron.

The rôle played by the various constituent elements is discussed in the preamble of the patent, and data typifying the high-temperature properties of such alloys are presented.

DURALOY COMPANY *Brit. Pat.* 848,043.
Similar to U.S. „ 2,857,266

High-Temperature Bearing Materials

Bearings or similar anti-friction elements having low coefficients of friction and destined for use at high temperatures are produced by incorporating into the working surfaces at least 50 (preferably 60) per cent. of nickel oxide and/or cobalt oxide. The bearings are preferably fabricated by sintering powdered nickel oxide and/or cobalt oxide with mullite or magnesia.

Among the examples described are nickel, 'Monel', or 'Inconel' bearings (which were oxidized in air at

1000°C. to form a nickel-oxide film) and those made from compacting, sintering and oxidizing mixtures of nickel powder with magnesium oxide or mullite.

MORGAN CRUCIBLE COMPANY, LTD.

French Pat. 1,230,518.

Inhibition of Corrosion of Aluminium-Nickel Alloys in High-Temperature Water

Corrosion of an aluminium-nickel alloy (containing 0·05–5 per cent. nickel, and, preferably, nickel 0·5–2·5, iron 0·5–1, silicon 0·1–0·2, per cent.) in water or in a dilute aqueous solution at 150°–350°C. is inhibited by adding silicic acid to the water in amounts ranging from 100 p.p.m. to that amount which produces saturation at the operating temperature and gives the solution a pH of at least 5·0. The presence of the silicic acid results in the formation on the alloy of a thin durable corrosion-resistant film of complex aluminium silicate.

The invention is particularly applicable to inhibiting the corrosion of aluminium-nickel fuel-rod sheaths in water-cooled nuclear reactors.

ATOMIC ENERGY OF CANADA, LTD.

Brit. Pat. 847,981.
Similar to French „ 1,204,092.

Stainless Steel Resistant to Stress Corrosion

A stainless steel, claimed to be resistant to stress corrosion, falls within the following composition range (preferred limits are given *in parentheses*): carbon up to 0·4 (0·2), chromium 12–40 (17–24), nickel 6–40 (7–20), copper 0·3–<1·0, per cent.

The principal advantage of the invention lies in the enhanced resistance to stress corrosion associated with the presence of copper in the range claimed.

AKTIENGESELLSCHAFT FÜR UNTERNEHMUNGEN DER EISEN- UND STAHLINDUSTRIE (inventor, C. CARIUS).

German Pat. 971,370.

Corrigendum

Nickel Bulletin, 1960, vol. 33, No. 12, p. 307.

Right-hand column, **Influence of Double Tempering on the Life of 'Ni-Hard' Grinding Balls.**

For Engineering, 1960, vol 190, No. 4, pp. 598–9,
read Engineering, 1960, vol. 190, Nov. 4, pp. 598–9.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Trade Marks*.

A comprehensive
private exhibition with films and lectures

will be held by

THE MOND NICKEL CO. LTD.

at the

ENGINEERS CLUB
ALBERT SQUARE
MANCHESTER

MARCH 18th, 20th - 22nd

INVITATION CARDS WILL BE SENT ON REQUEST

The exhibition will deal with the properties and applications of Nickel Alloys and related materials and will be of interest to Engineers, Designers, Metallurgists and Students

A Publication prepared by the
DEVELOPMENT AND RESEARCH DEPARTMENT
of
THE MOND NICKEL COMPANY LTD.

PRINTED IN ENGLAND BY WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1